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ular $MgCl_2$. Here the electrical conductivity of the solution is somewhat reduced while the rate of nerve conduction is much augmented. This is, of course, a striking instance of Loeb's law of the antagonism between a univalent and a bivalent cation; even though the bivalent cation in this case is magnesium, well known to be a depressant especially for muscular activity in *Cassiopea*.

A full report will appear in papers from the Department of Marine Biology to be published by the Carnegie Institution of Washington.

THE EARLIEST FRESH-WATER ARTHROPODS

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In the year 1900 Prof. T. C. Chamberlin published a prophetic paper under the title *On the habitat of the early vertebrates*.[1] In this paper he holds that the problem which he is considering admits of no other than hypothetical treatment, and proposes the hypothesis that "The chordate phylum is . . . . essentially from first to last a terrestrial race, whose main habitat was the land waters and the land itself, though still a race that sent its offshoots down to sea from time to time from the mid-Paleozoic onwards " (412). He arrives mainly at this conclusion on the basis that the fish form among animals could only have originated through mechanical genesis in swift streams and under a mode of life independent of the bottom. The most essential mechanical feature of rivers is their flow in a fixed direction, and to this insistent physical condition animal life had to adapt itself, for "otherwise the animal would be swept out to sea and its race be ended as a stream-dweller. It is different with ocean currents, for they return upon themselves and an animal may yield to them without losing its marine habitat" (406). This hypothesis is applied mainly to the origin of the fishes and less insistently to the eurypterids.

In regard to the origin of the eurypterids Chamberlin states: "From the occurrence of eurypterids first in marine beds apparently and later in fresh-water deposits it has been inferred that they were originally sea-dwellers and later became adapted to land waters, but the meagerness of their marine record on the one hand, and their abundance and fine preservation in the fresh-water deposits on the other, give point to the question whether their early marine record is anything more than the chance deposit of river forms borne out to sea" (403). But "it may be equally true that the fish and the eurypterids descended from the rivers to the sea in the mid-Paleozoic, though their remote ancestors may have ascended from it" (404). Finally, that the lands were clothed with vegetation even in Proterozoic time and that therefore there was an abundance of food in the rivers is attested in part by the great quantity of carbonaceous material in the strata of this time, plus the complete disintegration of the crystalline rocks as is shown by the fine aluminous muds, the clean sandstones, the great amounts of limestone, and the localized beds of iron-ore. Although arkoses are present (broken up and undecomposed granites), their mass is insignificant in comparison with the quantity of the other sedimentaries.

Early in 1916 Prof. Joseph Barrell also considered the probable first habitat of fishes, but from the standpoint of their occurrence as fossils in the rocks, in papers entitled *Dominantly fluviatile origin under seasonal rainfall of the Old Red Sandstone* and *Influence of Silurian-Devonian climates on the rise of air-breathing vertebrates.*[2] He agrees with Chamberlin and concludes that it is probable "that fishes arose in land waters" and "as such they constituted primarily a river fauna." The lung-fishes arose under semiarid climates and seasonal waters. "The exposure of the tidal zone alternately to water and to air had, then, nothing to do with the origin of lungs." "The evidence is regarded as strong that the air-bladder was originally developed as a supplemental breathing organ, although in modern fishes it has been mostly diverted to other uses. Among certain Devonian fishes, living under more and more strenuous climatic conditions of seasonal dryness, the use of the air-bladder for respiration became essential, and with the diminishing availability of the waters of certain regions the gills in those species which survived this crisis in evolution became correspondingly atrophied. The amphibians thus arose under the compulsion of seasonal dryness." Finally, "Climatic oscillation is a major ulterior factor in evolution" (388–391).

Later in 1916 appeared a suggestive memoir entitled *The habitat of the Eurypterida*, by Dr. Marjorie O'Connell,[3] which has stimulated the writing of these remarks. This work seeks to point out the actual habitat of eurypterids during the Paleozoic, as derived from a study of their entombment in all places Paleozoic, but chiefly in America and Europe. It is replete with paleontologic information, and all of the more important occurrences of these animals and their immediate associates are described in as much detail as the author was able to glean, in the main from the widely scattered literature, though she is also familiar with the actual field relations in the state of New York. There are in all the world about 130 described species in 14 genera, with the acme of development in the upper part of the Silurian where about 40 forms are known. There is very little evolution after Devonian time. On page 9 of Doctor O'Connell's memoir is given in italics the summation of her studies: *The eurypterids throughout their entire phylogenetic history lived in the rivers.* Lest the reader forget this thesis it is repeated on many subsequent pages. Though the book is argumentative and positive, and at times pleading in behalf of its theme, prying into and tearing apart all things eurypterid, the style remains essentially scientific.

It has been and still is widely held that eurypterids were marine animals previous to the Devonian, that toward the close of the Silurian they became euryhaline or able to live in both salt and brackish water, and that after Silurian time they probably became wholly restricted to the fresh water of the lands. Even though they were regarded as marine animals, living associated with trilobites and brachiopods, it has long been a difficult problem to explain why their remains are so very rare in the normal marine faunas of the Upper Cambrian, Ordovician, and Silurian, and even when they do occur are almost always in fragments. Although Doctor O'Connell points out this condition of occurrence, she does not make of it the strongest point in her argument, and yet it is the one fact that seemingly cannot be explained away. On the other hand, the entire specimen of *Strabops thacheri* at Yale has attached to the slab two specimens of the brachiopod *Obolus lamborni* and a poor head of a trilobite; the entombment is in a magnesian limestone, and because of the marine fauna of the same formation as listed by Beecher, one still retains the impression that this oldest and most generalized eurypterid may at least have been an inhabitant of the sea if not born of it. In the earliest deposits of the Silurian (Shawangunk) the eurypterids usually occur in fragments and in young specimens in thin and localized black shales, interbedded in a very thick and regularly bedded sandstone series, the material of a delta spreading into the epeiric sea. These beds are otherwise almost unfossiliferous, having associated with the eurypterids only Arthrophycus, a lobworm-like burrow that in the Medina formation is associated with marine fossils, showing that the Shawangunk is not a river flood-plain deposit but the sands of a delta under the influence of marine waters. On the other hand, in the latest Silurian formations of America, which are clearly not of normal marine waters, the eurypterids either have no marine associates or there are scattering specimens of cephalopods (Orthoceras, Trochoceras), bivalve crustaceans (Leperditia), and brachiopods (Lingula); in Bohemia, the middle Silurian, with a normal marine fauna of many species, has seven to eight forms of Pterygotus and one of Slimonia, but all of the specimens are in fragments. On Oesel, however, the three or four species of eurypterids are beautifully preserved in fine-grained gray dolomites or dolomitic limestones, with the original chitin of the animals still preserved; in fact, they have been etched out of the matrix and the tests mounted in Canada balsam. Here (at Attel) they are associated with an abundance of *Leperditia angelina*, *Orthoceras tenue*, and great stony heads, 2 feet across, of the hydroid Clathrodictyon (Twenhofel 1916). Surely these deposits are more of marine origin than of fresh waters.

All of this evidence, however, the present writer grants, does not necessarily prove that the eurypterids were born of the sea and continued to live in this environment until the close of the Silurian, for if this was their habitat, surely we should get good remains of them oftener than we do in the many normal marine formations of the Paleozoic, and especially in the Trenton and Niagaran formations. It would seem that, if the eurypterids were wholly marine animals in the Ordovician and especially in the Silurian, they should be as common and as well preserved as, for instance, the marine trilobites. This is not at all the situation. On the other hand, the evidence does not exclude the eurypterids from having also lived, at least at times, in brackish waters, the embayments of deltas, a conclusion that Doctor O'Connell will have none of. Nevertheless, we shall have to accept her main conclusion that the eurypterids were fresh-water animals, but with this modification, that they also appear to have lived at times in the brackish waters of more or less large bays and possibly in limited numbers even in the seas, just as some of the fresh-water fishes of the past have gone to sea. Whether they were born of the fresh waters or the ocean still remains a debatable question, though the evidence appears to favor strongly the former habitat.

It is a well-known fact that ceratiocarids and especially ancestral limulids and apodids are either very rare or occur locally in much restricted beds, and these, like the eurypterids, appear to have been entombed in the marine deposits near shore. The sporadic occurrences of the eurypterids and their great rarity as good specimens in normal marine deposits lead Doctor O'Connell to believe that these animals are of fresh-water habitats and that they were floated by the Paleozoic rivers into the open sea-ways just as we see the land animals and plants of today transported into the seas and oceans. On the other hand, her idea of delta deposits appears to be that they are either wholly of the land or of the sea, and her sketch of the late Silurian Bertie and Herkimer deltas (page 116) bears out this too rigid conclusion. More-over, the illustrations of the Mississippi delta in our text-books are on so small a scale as to give an erroneous conclusion as to the amount of the river flood-plain area. A large-scale map shows that 50% or even more of this delta is under the waters of the Gulf of Mexico, and in areas like Lakes Ponchartrain and Borgne the largest of eurypterids may have dwelt. Hence it will always be very difficult to separate the deposits of such areas, with their mixed biotas, from those of the river flood-plains on the one side, and on the other from those of the more or less marine bays.

In this connection we should not neglect to state that nearly all the eurypterids occur in strata of times when the continents were largest and when the rivers were rejuvenated to stronger and longer flow into the interior seas. Also that Eurypterus lived from Ordovician into Permian time, and Pterygotus was distributed almost throughout the world during the Siluro-Devonian. However, at the times when the seas have their greatest spread we find almost no merostomes of any kind. These are significant facts bearing upon the probable habitats of the Paleozoic merostomes.

Since it appears that the eurypterids are probably in the main fresh-water animals, and as some of them take on the form of scorpions and may therefore be spoken of as river scorpions, this admission opens a most wonderful vista into the probable life of the land during early Paleozoic times, as far back at least as the Upper Cambrian. There are other merostomes of the order Limulava (two genera) in the Middle and Lower Cambrian, and these antennate forms are more directly related to the eurypterids. Of the Synxiphosura, forms ancestral to the Xiphosura, the Middle and Upper Cambrian have at least four genera. As all of these animals also appear to have lived in fresh water, it would seem that the rivers of Cambrian time were peopled by merostomes none of which exceeded 6 inches in length, but in late Silurian time they were not only far more varied in form, but Pterygotus at least, the most active and predaceous of them all, attained a length estimated at from 6 to 9 feet. Stylonurus, the great spider-like eurypterid of the Devonian rivers, may have attained a similar length. In regard to these and other eurypterids, Clarke and Ruedemann,[4] the authorities on these arthropods, think that most of our museum specimens are immature individuals, and often the casts of tests, conditions further favoring the theory that they are fresh-water animals whose thin, light tests were easily drifted by the rivers into the estuaries and the seas. The considerable variety and the great size attained by some forms means that there was an abundance of food, both animals and plants, in the rivers of Paleozoic time. Some of the animals were the smaller eurypterids, in the Ordovician and Silurian the armored fishes (the ostracoderms), in the Silurian the additional lung-fishes and diminutive primitive sharks (the acanthodians), and in the Devonian, large bivalve molluscs. However, there appear to have been still other arthropods present, such as the ceratiocarids, a stock of phyllocarids, the ancestral limulids (Synxiphosura), and probably also the branchiopod apodids. In the final analysis we must further admit that all were more or less directly dependent upon an abundance of plant food. and therefore that the early Paleozoic lands were clothed with vegetation, none of which is as yet certainly known to paleontologists. In this connection, however, we must also point out that today in no fresh waters are invertebrates of any kind known attaining to 9 feet long or even half that length, although it takes living Limulus eight years to attain to sexual maturity. This implies that at least some of the Silurian and Devonian eurypterids reached a great age, and, living in the rivers, and maybe at times in the brackish-water bays, were the monarchs of their environment. On the other hand, if the smaller merostomes had lived in the sea, as did the trilobites, they would also have been fed upon by the armored cephalopods, the nautilids, and we may have evidence of this preying in the common association of Orthoceras with the eurypterids. Having no enemies to feed upon them in the rivers, and none that were more agile, more powerful, or more cunning until Devonian time, the eurypterids of the Silurian and early Devonian continued to live on for a long time and so attained to a far greater size than any of the fresh-water invertebrates of today, which are dominated by the more active and intelligent river fishes. With the ascendancy of the fishes beginning in the Devonian, we see a diminution and lack of structural change in the eurypterids and the trilobites, and the vanishing of both stocks in the Permian.

The argument of faunal associates and their entombment, plus the nature of the deposits, used by Doctor O'Connell to prove that the eurypterids are fresh-water animals, will also apply to the ceratiocarids, the limulids, and the apodids. In the Middle Cambrian, Walcott has collected three genera of ancestral limulids and other merostomes (Limulava) in blue to black muds rich in kaolin, which were "probably laid down in a small bay or lagoon in close connection with the shallow Middle Cambrian sea." In these deposits trilobites of the genera Agnostus, Microdiscus, Neolenus, Ptychoparia, etc., are fairly common.

It may therefore be that the Limulava, the ancestral limulids, and the apodids were in this case also fresh-water animals drifted by the streams into the lagoon. If so, this is evidence of fresh-water life as far back as the Lower Cambrian. Further, in the uppermost Cambrian at one locality in Wisconsin the present writer has collected a few fragments and one entire specimen of the ancient limulid Aglaspis in association with an abundance of trilobites, fragmented and entire, and many well preserved brachiopods (*Westonia stoneana*). In all later Paleozoic deposits the limulids are almost always associated with eurypterids, and practically never in normal marine faunas. They are always very rare fossils until early Pennsylvanian time, when *Euproops danæ* is common in that most interesting mixed estuarine and terrestrial fauna preserved in the nodules of Mazon Creek, Illinois. The Triassic limulids also appear to have lived in fresh water, but since late Jurassic time Limulus has been in the sea, and is represented today by several living species in the Atlantic and Pacific oceans. Can, therefore, the annual return of these animals to the land to lay their eggs be a surviving instinct and an ontogenetic expression of their earlier, fresh-water habitat?

In this connection should be recorded a most interesting observation of Limulus made by Professor Barrell many years ago. He took home in the spring of the year a large female Limulus that he had picked up on the shore of New Haven Bay, and kept it in the grassed yard back of the house in which he lived. Under these conditions the animal was still able to crawl about feebly for two days and gave evidence of life for about a week, during all of which time it was out of the water. This clearly indicates that the gill-books are fairly easily adaptable to air-breathing, and the question may be asked whether in the Paleozoic during times of drought ancestral limulids of the fresh waters may not have lived over the dry season, as do the lung fishes of today, buried in the mud and breathing the air.

Attention should also be directed to the occurrences of the Apus-like branchiopods, the oldest of which is Protocaris of the Lower Cambrian, known in a single specimen associated with trilobites in a marine deposit laid down, however, near the shore. In the Middle Cambrian black shale lagoon deposits (Burgess), there are three genera, and then we have no record of them again until Apus is met with in the Triassic—henceforth a persistent synthetic genus, which in the living world is restricted to the more or less evanescent land waters of many continents.

If the eurypterids and limulids arose in the fresh waters, as appears probable, we can then the more readily explain why they and the terrestrial scorpions do not pass through a crustacean nauplius stage, for they had to adapt themselves to the lands or to waters limited in distribution and more or less evanescent in continuity, to the streams that flowed constantly in one direction and eventually into an unnatural habitat, the sea. They needed a more direct and quicker embryonic development, requiring, it would seem, the abandonment of the nauplius stage. It may therefore well be that the trilobites retaining the nauplius stage did not give rise to these stocks, as is sometimes assumed. We may have to look for this ancestral stock in one still more primitive, and the Protocaris-Apus line of branchiopods suggests itself, but whatever the stock, it would seem to have permanently invaded the rivers of the land either in Proterozoic time, or that postulated intermediate stage in the earth's history previous to the Cambrian but of which we have not a trace of direct evidence, the Lipalian time of Walcott.

[1] T. C. Chamberlin, *Jour. Geology*, 8, 400-412 (1900).

[2] J. Barrell, *Bull. Geol. Soc. America*, 27, 345-436 (1916).

[3] M. O'Connell, *Bull. Buffalo Soc. Nat. Hist.*, 11, No. 3, 1-277 (1916).

[4] J. M. Clarke and R. Ruedemann, The Eurypterida of New York, *Mem. New York State Mus.*, No. 14 (1912).

OBSERVATIONS UPON TROPICAL FISHES AND INFERENCES FROM THEIR ADAPTIVE COLORATION

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The conception that species have been multiplied by divergent evolution of related strains is based upon a great body of verifiable observations. Sound judgment has not been exercised consistently, however, in the attempt to establish the fact that their development has been directed throughout by natural selection.

If the Darwinian hypothesis is true, the characters of organisms should be largely of an adaptive sort, but its adherents have failed, upon the whole, to distinguish between shadow and substance, and have been content to support their position by *imputing* utility to structures and habits, when nothing less than rigorous proof of the fact will suffice. It is not demonstrated, for example, that any class of markings serves for purposes of recognition, or for signalling between individuals of one species. Neither is it proved that some color combinations warn off possible enemies, nor, indeed, that any type of pigmentation is functionally conspicuous. The last assumption, nevertheless, underlies a series of suggestions whose apparent conformity with its terms is held to support the hypothesis of natural selection.